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NUMBER 1

SOME QUALITATIVE RESULTS ON THE ELECTRIFICATION OF SNOW¹

BY D. C. PEARCE² AND B. W. CURRIE

Abstract

This paper reports on observations of the electrical charges on falling and drifting snow, and gives the results of laboratory experiments designed to determine the relative importance of possible charge-producing mechanisms in the atmosphere when snow and ice crystals are present. These mechanisms include impacts of snow particles on one another, melting of snow as it falls, and condensation of water vapor and formation of rime on falling snow. Apparently a large fraction of the snowflakes falling during the cold part of the winter in Saskatchewan has a charge less than 2×10^{-4} e.s.u. per flake. During blizzards the snow particles blowing along or just above the hard surface of the drifted snow carry a net negative charge and the air at the 1 m. level has positive space charge densities that are from 10 to 100 times the normal, positive space charge density. Very large charge separations can occur when a snow surface is eroded by an air blast and when snow is blown against snow and metal surfaces, a resultant negative charge appearing on the heavier particles and the corresponding positive charge on either very small ice particles or ions. This charge-producing mechanism is most effective at high air velocities and at low temperatures. The melting of newly fallen snow under conditions favorable to the escape of air bubbles does not show a charge separation. Condensation of water vapor and formation of rime on snow surfaces result in only very small charge separations for the conditions readily obtained in laboratory experiments.

Introduction

Large, and sometimes rapid, separations of electrical charges are known to occur in the atmosphere when snow particles are present, and when the presence of snow particles is surmized. Steady streams of sparks can be drawn from the lead-in wires to radio receivers and sometimes from stoves and other metal objects inside buildings when they are connected electrically to objects exposed to blizzards (3). On such occasions, positive electric fields (corresponding to a negatively charged earth and a positively charged atmosphere) as high as 10,000 v. per m. have been measured at levels close to the earth's surface (7, p. 62). Electrical discharges to the air from an aircraft that is flying through clouds of snow often make radio reception on the aircraft either difficult or impossible. It is generally agreed that the upper part of thunder clouds consists of ice crystals and that these ice crystals are required for the formation of raindrops (1). Since lightning discharges

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begin at about the same time as the raindrops start to fall, the possibility exists that the ice crystals are a factor in the development of the large electric fields required for the discharges.

Practically all investigators in this field have assumed that the snow rather than some associated meteorological condition is essential to the charge-producing mechanism. Starting with this assumption, a number of different physical processes by which the charges may be produced and then separated have been suggested, although both observational data from the atmosphere and experimental data from the laboratory in support of these suggestions are either lacking or inconclusive. They include, (a) small-scale separations of charges due to impacts of snow particles on one another that are followed by large-scale separations due to differential gravitational and turbulent actions on the charged particles; (b) escape of charged air bubbles from snow particles as they melt on their way to the ground; (c) condensation of water vapor on snow particles with the particles acquiring charges of a sign different from that of air, the fall of the particles giving the large-scale separation; and (d) formation of rime on snow particles, the fog particles that constitute the rime having charges predominantly of one sign and the large-scale separation taking place as in (c). Obviously, (a) is the only process that is applicable to all the aforementioned cases of charge separation, (b), (c), and (d) playing no effective part in the electrical phenomena of blizzards.

Process (a) was suggested originally by Simpson (8) as a probable explanation of the large electric fields that he had observed in Antarctic blizzards. Recently, he has described the process in greater detail, and indicated its possible application to thunderstorm electricity (9). Essentially, a resultant negative charge should appear on snow particles after impacts with one another, the equivalent positive charge appearing on either small ice particles or ions that can be carried upward by air currents or left behind as the heavier particles fall. The few sets of observations that have been made on blowing snow are either contradictory or limited to one level in the atmosphere (9, 10, 11, 12). Laboratory experiments to see if snow particles charge by impact have apparently never been made.

Process (b) has been demonstrated for ice from distilled water that had been rapidly frozen (4). Air, drawn from above the melting ice, was charged owing to the escape of small, charged air bubbles that had been entrapped in the ice. Evidence does not exist that this process occurs as snow particles melt.

Processes (c) and (d) have been demonstrated in laboratory tests with frost and rime formations on metal and ice surfaces (2, 5, 13). The physical conditions involved in the observed electrifications are uncertain. In addition, no direct evidence exists that a corresponding electrification occurs on snow particles or surfaces.

Winter weather conditions in the Prairie Provinces of Canada are particularly suitable for the examination of these processes. Falls of light, fluffy snow that is readily drifted by the wind occur at frequent intervals. Occasionally the drift reaches blizzard proportions, when the air is filled to a height of 100 ft. or more with flying particles of snow. In addition, snow that has not been modified by some melting either on its way to the surface or at the surface is available for experimental work during at least three months of the year.

Process (a) was investigated by measuring the charges on individual snowflakes as they fell to earth, and the resultant charges during blizzards on snow blowing along or immediately above hard-packed drift snow and on snow particles and ions at the 1 m. level. Additional information on this process was obtained by eroding snow surfaces with an air blast and by blowing air through and over snow surfaces and then measuring the charges that were developed. Process (b) was tested by melting newly fallen snow under conditions similar to the ones that give a charge when ice is melted. Processes (c) and (d) were tested by drawing saturated air and air containing fog particles past blocks of snow and measuring the charges acquired by the snow.

Experimental

Charges were measured by means of a Lindemann electrometer, its portability and the ease with which its sensitivity could be changed making it convenient for the work on snow. In addition to all the usual precautions to avoid spurious effects due to stray and contact potentials, special care was taken to prevent condensation of moisture on insulators at low temperatures, the moisture coming mostly from the observer's breath. Wherever artificial heat could not be used for this purpose, ceresin wax proved a much better insulator than other materials. Where a low capacity was not a vital consideration, coaxial cable was used to connect experimental equipment to the electrometer.

Charges on Falling Snow

The snow receiver, shown in Fig. 1, was essentially a Faraday chamber with an opening at the top into which the snow could fall. It was supported by a cylindrical block of sulphur that was wound with several turns of resistance wire through which a current was passed to keep the surface of the sulphur dry. Both the receiver and the lead to the electrometer were shielded from the earth's electric field and other stray fields by grounded, metallic casings. The receiver was mounted on the roof of a low hut that was so located that the turbulence about neighboring buildings would not appreciably affect the representativeness of the catch. The receiver was also surrounded by a shield of heavy cotton to minimize the effects of turbulence due to the receiver itself.

Observations of the charges on individual snowflakes and ice crystals were made during nine storms in December, 1947, and January, 1948, the air

temperatures varying from a low of -2°F. to a high of $+22^{\circ}\text{F.}$, and the wind velocities from a low of 7 m.p.h. to a high of 24 m.p.h. Charges as low as 2×10^{-4} e.s.u. were detectable. Visual observations of the snow entering

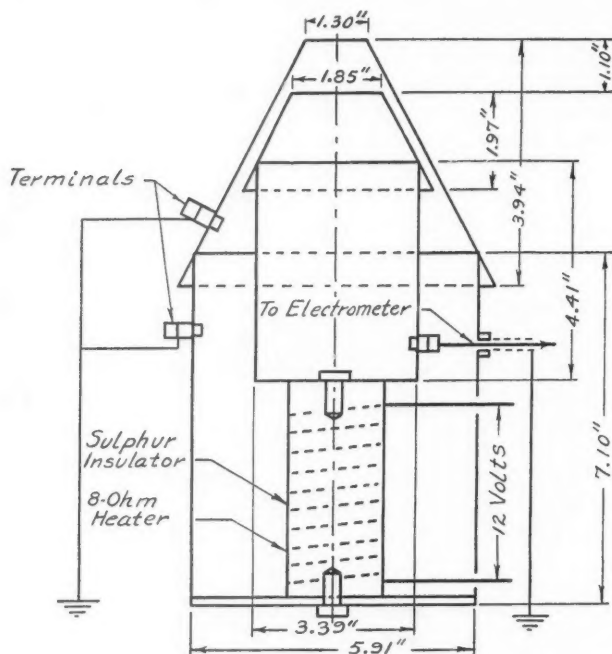


FIG. 1. Receiver for measuring the electrical charges on snowflakes.

the receiver, as the charges were measured, showed that a very large number of the particles were neutral or had charges less than the detectable value. For the particles with charges that could be measured, the average charge was $+9 \times 10^{-4}$ e.s.u. The maximum observed charge on a single flake was $+4.5 \times 10^{-2}$ e.s.u. During each storm, both positively and negatively charged particles were observed, the ratio of the former to the latter being equal to 1.9 (particles with charges below 2×10^{-4} e.s.u. being neglected). A preponderance of negatively charged flakes occurred on one occasion when the wind velocities were high and the possibility existed that particles swept upward from the roof of the hut were entering the receiver.

Charges on Drifting Snow

For snow blowing along the surface, condenserlike cups were placed in metal pails with small openings in their lids so that snow could fall into the cups. The pails were placed in small excavations on the leeward sides of

drifts, so that practically all the snow falling into a cup had been wind driven and only in contact with snow and air. Any charge transferred to the cup by the snow remained as a bound charge until it either leaked through the dielectric to the outer plate, or was neutralized by connecting the inner plate to ground. To make a measurement, a cup with its catch was placed on a metal plate connected to the electrometer. The inner plate of the cup was then grounded. This caused an electrometer deflection proportional to the charge on the snow. The observations on all except one occasion showed that the drift snow (caught in this way) had a negative charge. The exception occurred when the air temperature was above 32°F . and the snow temperature was below 32°F . Although the observed magnitudes of the charges varied greatly because of the changing intensity of the drift, they indicated an increasing separation of charge with increasing wind velocity, and with decreasing temperature.

In order to measure the charges at the 1 m. level in the drift, the device shown in Fig. 2 was used. Air was drawn through it at constant and known rates, snow particles and ions in the air stream being trapped by copper

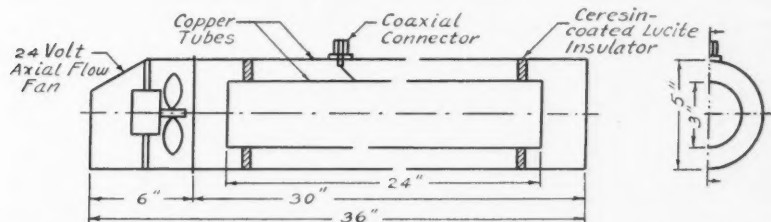


FIG. 2. Device for measuring the space charge density in the air. Copper turnings placed in the inner tube were used to trap ions and ice particles in the air.

turnings inside the inner copper tube. On occasion, the larger particles were removed from the air stream by placing either cheesecloth or metal screens over the end of the electrostatic shield. The tube was mounted with its axis horizontal and at a height of 1 m. The space charge density was computed from the charge acquired by the tube and electrometer in a known time and the rate of flow of the air. Since the space charge density in the atmosphere is normally positive, numerous measurements were made at different times and under various weather conditions to determine the values that occur when snow is not drifting.

The average space charge density at Saskatoon during daylight hours for a period from the third week of February to the second week of April was $+3.6 \times 10^{-8}$ e.s.u. per cm^3 . In computing this average, all observed values when either ice crystals or fog droplets were visible in the atmosphere and when snow was drifting were excluded. As soon as the surface snow started to drift or falling snow was broken as it hit the surface and then started to drift, the space charge density became strongly positive, values as high as

$+ 10^{-5}$ e.s.u. per cm^3 occurring with moderate drift. With very strong gusts the rate of charging of the collector either decreased or changed its sign temporarily, indicating that the proportion of negatively charged particles entering the collector increased at such times. In addition, there was some indication that the space charge densities were greatest during drifting with the lowest temperatures. The observations with layers of cheesecloth over the open end of the collector showed conclusively that large particles of snow were not responsible for the positive space charge. Similar observations with a metal screen, consisting of a layer of copper turnings between two wire grids, indicated that the positive space charge was not due to a separation of charges by impacts of ice particles on copper with the negative charge being carried through the copper turnings by the air stream.

Electrification by Use of an Air Blast

Qualitative verification of the observations on drifting snow was obtained by eroding the surface of a snow block by an air blast. The snow block was placed on a copper tray, and air at a pressure of 25 p.s.i. and about the same temperature as the snow was directed against its upper surface through a $\frac{1}{4}$ in., grounded brass tube. The charges on the visible particles swept off the block, on air and small ice particles that could be sucked upward from above the eroding snow surface and into the device for measuring space charges, and on the block were measured. The particles swept off the block carried a net negative charge, the air and any small ice particles sucked into the collector carried a net positive charge, and the block was left with a positive charge. The magnitudes of the charges varied directly with the intensity of the erosion and the amount of the snow swept off the block, and decreased with increasing temperature. The positive charge on the block was apparently due to positive ions, or small ice particles with positive charges, that were driven into the air spaces in the snow block by the air blast.

The possibility that an appreciable charge separation could result by friction between air and snow without fracture of the snow or collisions of snow particles was eliminated by the following tests. An air-tight Faraday chamber, except for two quartz tubes by which air could be sucked through the chamber, was connected to the electrometer. The first test consisted of packing the inner end of one quartz tube with snow so that air had to pass through the snow before it could enter the chamber; the second consisted of placing a block of snow inside the chamber so that the incoming air blast struck it at a glancing angle; and the third consisted of placing loose snow in the chamber so that the incoming air was sucked through it before leaving the chamber. Invariably, charging was not detected in any of the tests until the air velocity was increased sufficiently to fracture the snow surfaces or to cause a motion of the snow particles relative to one another. As soon as such a fracture or motion took place, negative charges beyond the range of the electrometer were observed.

Still another series of tests involved the blowing of snow along a copper plate, against a copper plate, and against blocks of drift snow. Small negative charges were observed on both the copper plate and the snow in the first case, the corresponding positive charge apparently being carried away in the air stream. In comparison, very large negative charges were observed on the copper plates, the snow blocks, and the projected snow in the impact tests, the corresponding positive charges again apparently being carried away by the air.

Charges on Melting Snow

A beaker containing either a sample of snow or ice was placed inside a Faraday chamber. Heat sufficient to melt the snow or ice was obtained by pouring warm water into the space surrounding the beaker. A steady stream of air was drawn over the snow or ice by means of an air-pump, the connections to the air-pump and the open air being made by quartz tubes fastened into the walls of the Faraday chamber. Tests of the original observations of Dinger and Gunn (4) on melting ice were made by quickly freezing several grams of distilled water in a beaker, placing the beaker in the chamber, and measuring the charge acquired by the Faraday chamber as the ice melted. Invariably a positive charge was observed. On substituting snow for the ice no charge was detected. Various samples of newly fallen snow, drift snow, and old snow from the bottom of drifts where grains of ice were beginning to form were used.

Charges Resulting from Frost Deposits on Snow

The charging effect of deposits of hoarfrost and of rime on a snow surface was measured by placing a small block of drift snow on an insulated metal plate inside a Faraday chamber, and then drawing either moist air or air filled with small water droplets through the chamber. The charge due to the frost deposits on the snow and the inner surface of the chamber was measured by connecting the chamber directly to the electrometer, and on the snow by connecting the metal plate to the electrometer and grounding the chamber. A small charge (usually positive) appeared during the first few minutes of each test, reached a maximum value, and then disappeared apparently owing to the melting of the frost deposits by the heat transfer to the metal and snow surfaces from the air. However, large variations in the rate of charging and even negative charges were occasionally observed. Presumably these were due to the lack of controlled temperatures, the temperature of the metal and snow surfaces depending on the out-of-door temperatures at the time of the test. In addition, the air temperature was always above 32° F. when it entered the Faraday chamber.

Results

The aforementioned observations indicate that process (a) operates during blizzards, and probably in any atmospheric condition where snow particles can strike one another, or other objects; that process (b) does not operate

when the precipitation is in the form of melting snow; and that processes (c) and (d) can take place when the snow is in the form of an extended surface. The mechanism by which the initial charge separation takes place in process (a) evidently involves fractures of the snow particles, since ordinary frictional interactions between snow and air, and snow and metal, give only very small charge separations. The effectiveness of (a) increases with increasing wind velocity and decreases with increasing temperature. The fact that about twice as many falling snowflakes carry positive charges as negative charges is unfavorable to the view that process (a) operates in thunderstorms. Although the highest wind velocity (24 m.p.h.) at which charges were observed on falling snowflakes was much smaller than velocities occurring in thunderstorms, the increased turbulence close to the surface must have greatly increased the probability of collisions. Since a preponderance of negatively charged flakes was not observed, it is likely that the particles in a snow cloud either do not collide with one another or do not collide with sufficient relative velocities to cause charge separation.

Acknowledgment

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